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SILICON

By Joseph Gambogi

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U.S. DEPARTMENT OF THE INTERIOR

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SILICON

U.S.
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BUREAU
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MINES

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COVER PHOTO:
Silicon metal is used to produce a variety of silicon-base polymers. Among these materials, silicone rubber is used as a sealant for both domestic and commercial applications. This photo illustrates silicone rubber sealant being applied to the exterior of a house. (Photo is courtesy of GE Silicones.)

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SILICON

By Joseph Gambogi

Mr. Gambogi, a physical scientist with more than 7 years of Government and industry experience, has been the commodity specialist for silicon since 1988. Domestic survey data and trade data were prepared by Ms. Robin Johnson, Mineral Data Assistant in the Branch of Data Collection and Coordination.

For most of 1989, demand for silicon products remained near the high levels reached in 1988. However, a reactivation of idle capacity, combined with new global capacity, resulted in an oversupply of silicon materials. Prices that had reached record highs in 1988 decreased significantly. Consequently, production cutbacks were scheduled by several domestic producers in the second half of 1989.

LEGISLATION AND GOVERNMENT PROGRAMS

Several proposals were introduced in the 101st Congress that would limit the amount of sulfur dioxide emissions from coal-based power utilities. The Bureau of Mines conducted a study to determine the possible effects of these proposals on the minerals industry. The study found that, if passed into law, significant cost increases could be incurred by certain utilities. These costs would in turn be passed along to their consumers, which included several silicon and ferrosilicon producers. The study estimated the legislation proposed would increase the average cost of production from 2 to 4.5 cents per pound of contained silicon metal. At yearend, a resolution regarding this legislation had not been reached.[1]

Under Title III provisions of the Defense Production Act, the Air Force System Command awarded two contracts totaling more than $33 million to encourage development of commercial suppliers of metal matrix composites (MMC). The contracts were awarded to Advanced Composite Materials Corp., Greer, SC, and DWA Composite Specialties Corp., Chatsworth, CA. The Air Force indicated the goal of the program was to make MMC materials "market competitive."[2] Aluminum matrix composites with silicon carbide fiber reinforcement appeared to show the most promise for achieving this goal.

STRATEGIC CONSIDERATIONS

Silicon semiconductors played an essential role in electronic devices for military and commercial applications. In 1989, the United States was one of the world's leaders in semiconductor device manufacture. However, portions of the domestic semiconductor market were dominated by imports. An area of significant concern was the domestic capability to produce infrared (IR) detector-grade silicon metal. IR detector-grade silicon was used by the Department of Defense for the manufacture of devices that guide highly advanced weapons. IR materials also served numerous functions as part of satellite surveillance systems. Nevertheless, these materials were obtained almost exclusively from foreign sources in 1989.[3]

PRODUCTION

Overall gross production and shipments of silicon containing products were comparable to those of 1988. Overall production increased 4% while shipments were nearly unchanged. However, production and shipments of

TABLE 1

PRODUCTION, SHIPMENTS, AND STOCKS OF SILVERY PIG IRON, FERROSILICON, AND SILICON METAL IN THE UNITED STATES IN 1989

(Short tons, gross weight, unless otherwise specified)

Material	Silicon content (percentage)		Producers' stocks Dec.31, 1988[r]	Gross production	Net shipments	Producers' stocks Dec.31, 1989
	Range	Typical				
Silvery pig iron	5–24	18	W	W	W	W
Ferrosilicon	25–55	48	51,687	377,974	294,521	60,841
Do.	56–95	76	13,948	137,593	110,143	22,692
Silicon metal (excluding semiconductor grades)	96–99	98	6,875	154,268	146,573	9,666
Miscellaneous silicon alloys (excluding silicomanganese)	32–65	—	15,111	90,561	77,309	22,293

[r] Revised. W Withheld to avoid disclosing company proprietary data.

certain products changed significantly. The most significant change occurred in production and shipments of 75%-grade ferrosilicon. Shipments of this product rose 28%, while production rose 56% compared to that of 1988. Producer stocks of silicon-containing material rose 32% overall. Estimated ferrous scrap consumption was 275,000 tons in 1989.

Globe Metallurgical Inc., Beverly, OH, purchased Materials & Methods Ltd., Reigate, England. Materials & Methods held several patented processes used to produce foundry ductile iron. Many of these processes used silicon ferroalloys, which Globe produced at its operations in the United States. This was Globe's first major acquisition since its management buyout in 1987. By mid-year, Globe terminated its 34-year-old relationship with its sales representatives, Pickands Mather & Co., to form an internal sales force. Late in 1989, Globe shut down one of its 13-megavolt-amphere (MV•A) ferrosilicon furnaces for repair.

Following a financial reorganization in 1988, Simetco Inc., Montgomery, AL, bought Quadracast Inc., and its Harrison Handling Division. Quadracast specialized in metals fabrication. Harrison built patented belt conveyors and other equipment used in the mining industry.

Silicon Metaltech Inc., Wenatchee, WA, expanded its operations in Rock Island, WA, with the construction of a new chemical lab. The new facility allowed the company to perform detailed analyses of silicon metal. This type of analysis was essential for Silicon Metaltech to produce chemical-grade silicon metal.

Cominco American Resources Inc. rekindled an idle ferrosilicon furnace at its Glenbrook Ferronickel Operations where ferrosilicon was consumed in the ferronickel process. The company reported some of the furnace's 18,000 short tons per year (tpy) of capacity was intended for commercial sales. For most of the year, Cominco American Resources was a wholly owned subsidiary of Cominco Resources International Ltd. and USA Investments. However, Cominco International purchased the remaining Cominco American interest late in 1989.[4]

In September, American Alloys Inc. began production of silicon metal at its New Haven, WV, plant. The new furnace was reported to be capable of producing 6,000 tpy of contained metal. The furnace represented the first new addition to the company, which was formed in a management buyout of Foote Minerals Co. in 1987.[5]

In June, Elkem Metals Co. temporarily idled a ferrosilicon furnace at Ashtabula, OH, after a burnthrough in the furnace lining. The furnace was brought back on-line in October after maintenance repairs had been completed. Late in the year, Elkem Metals announced plans to shut down one of two furnaces at its Ashtabula, OH plant.

Several companies made plans late in 1989 for reducing output of silicon products during 1990. Among these companies, SKW Alloys Inc. planned to shut down one of two 35-MV•A ferrosilicon furnaces at its Calvert City, KY, plant. Meanwhile, Globe Metallurgical also planned to shut down individual furnaces for maintenance during 1990.

Monsanto Electronics Materials Co. (MEMC) was sold to Huels AG of the Federal Republic of Germany. MEMC was the last major domestic silicon wafer producer catering to independent chip makers. All other major producers made wafers for their own chip production.[6]

TABLE 2

PRODUCERS OF SILICON ALLOYS AND/OR SILICON METAL IN THE UNITED STATES IN 1989

Producer	Plant location	Product
American Alloys Inc.	New Haven, WV	FeSi and Si.
Applied Industrial Minerals Corp.	Bridgeport, AL	FeSi.
Cominco American Resources	Riddle, OR	Do.
Dow Corning Corp.	Springfield, OR	Si.
Elkem Metals Co.	Alloy, WV	FeSi and Si.
Do.	Ashtabula, OH	FeSi.
Do.	Marietta, OH	Do.
Globe Metallurgical Inc.	Beverly, OH	FeSi and Si.
Do.	Selma, Al	Si.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi and silvery pig iron.
Reynolds Metals Co.	Sheffield, AL	Si.
Silicon Metaltech Inc.	Wenatchee, WA	FeSi and Si.
Simetco Inc.	Montgomery, AL	Si.
SKW Alloys Inc.	Calvert City, KY	FeSi.
Do.	Niagara Falls, NY	FeSi and Si.

CONSUMPTION AND USES

Apparent consumption (demand) of silicon-containing ferroalloys and silicon metal decreased 5% compared with that of 1988. The continued strong demand reflected high production levels in the aluminum, iron and steel, and silicon-base chemical industries. Specifically, consumption of silicon metal decreased 11% while ferrosilicon applications decreased 2%. The aluminum industry used silicon metal in the production of wrought and cast products while ferrosilicon was used as a deoxidizing and alloying agent in the production of iron and steel products. Ferrosilicon and miscellaneous silicon alloys used in the production of iron and steel accounted for 70% of all the silicon materials consumed, based on silicon content.

Metallurgical-grade silicon metal produced by tonnage methods was used as the basic raw material in the manufacturing of many chemical products and intermediates such as silicones and silanes. Silanes were used in the production of high-purity silicon for semiconductor devices and solar cells (photovoltaic cells). The Bureau of Mines did not collect data on electronic grades of silicon, which were relatively low in quantity but high in unit value.

Union Carbide Corp. reorganized its silicone fluids, silicone surfactants, and silanes business into a new worldwide operating unit called Organo-Silicon

TABLE 3

REPORTED CONSUMPTION, BY MAJOR END USE, AND STOCKS OF SILICON ALLOYS AND METAL IN THE UNITED STATES IN 1989

(Short tons, gross weight, unless otherwise specified)

Silicon content (percentage)	Silvery pig iron	Ferrosilicon[1]				Silicon metal	Miscellaneous silicon alloys[2]	Silicon carbide[3]
Range	5–24	25–55	56–70	71–80	81–95	96–99	—	63–70
Typical	18	48	65	76	85	98	48	64
End use								
Steel	24	122,220	—	87,550	818	1,761	2,263	210
Cast irons	17,739	125,962	1,147	15,209	336	([4])	22,862	22,304
Superalloys	—	([4])	—	260	([4])	117	—	—
Alloys (excluding superalloy and alloy steel)	([4])	4,105	—	([4])	([4])	54,997	47	—
Miscellaneous and unspecified	12	1,896	—	671	35	[5]142,334	1	—
Total reported	17,775	254,183	1,147	103,690	1,189	199,209	25,173	22,514
Consumers' stocks, Dec. 31	778	8,272	87	7,460	48	2,569	1,035	1,451

[1] Includes briquettes.
[2] Primarily magnesium-ferrosilicon but also includes other silicon alloys.
[3] Does not include silicon carbide for abrasive or refractory uses.
[4] Included with "Miscellaneous and unspecified."
[5] Consists primarily of consumption of silicon metal for the production of silicones and silanes and estimated consumption for the production of fumed silica and other chemicals.

Products, Systems and Service Group. The announcement follows a 1988 decision not to form a joint venture with General Electric Co. due in part to objections by the Federal Trade Commission. The new group made plans to expand its silane operations in Sisterville, WV, as well as its silicone facility at Italiba, Brazil. Union Carbide was one of the major consumers of chemical-grade silicon metal in 1989.[7]

PRICES

Following record high prices in 1988, published prices for silicon containing materials decreased significantly in 1989. However, overall demand for these products was only slightly lower than in 1988. Several factors contributed to an oversupply of material forcing lower market prices. One of the most influential factors affecting prices was the recent reactivation of idle U.S. capacity. Other factors affecting prices were the development of new production capacity in South America and the escalation of low cost imports from China, South America and the U.S.S.R. into the United States. Large stockpiles of Chinese material developed by Japanese consumers and traders in the second half of 1988 contributed to the fall in prices worldwide. The average published prices for silicon-base commodities are listed in the following table. All prices are posted in cents per pound of contained silicon.

Year	Si Met	50% FeSi	75% FeSi
1980	59.17	39.80	41.77
1981	61.04	41.54	40.01
1982	57.35	41.42	37.93
1983	53.77	37.12	36.67
1984	60.35	41.22	41.89
1985	58.77	37.52	35.71
1986[r]	56.32	35.55	33.65
1987	58.06	38.51	36.78
1988	68.67	52.08	56.82
1989	58.75	49.57	48.96

Source: Metals Week

FOREIGN TRADE

In 1989, several domestic producers increased their sales efforts in the global market. Meanwhile, global demand remained relatively high. As a result, ferrosilicon exports increased significantly compared with those of 1988. The major markets for ferrosilicon exports included Canada, the Republic of Korea, and the United Kingdom. In contrast to ferrosilicon, silicon metal exports decreased by nearly one half. This depression was believed to be caused by a saturation of Chinese material within the Japanese market. Exports of silicon metal were shipped primarily to Mexico, the Netherlands, and Venezuela.

Under the Omnibus Trade and Competitiveness Act (Public Law 100–418, Subtitle B), tariff schedules were revised on January 1, 1989, to conform to the internationally established Harmonized Tariff System (HTS). Consequently, U.S. customs import and export categories for silicon-base alloys were revised. The law was designed to enhance the competitiveness of the Nation's industries and to improve the management of the U.S. trade strategy. The revisions significantly changed the tariff categories for silicon-base products as shown on the following table:

Item	Harmonized Tariff Schedule Number	Most Favored Nation (MFN)[1]	Non-MFN[1]
Ferrosilicon, 55%–80% Si:			
More than 3% Ca	7202.21.1000	1.1% ad val.	11.5% ad val.
Other	7202.21.5000	1.5% ad val.	11.5% ad val.
Ferrosilicon, 80%–90% Si	7202.21.7500	1.9% ad val.	9.0% ad val.
Ferrosilicon, more than 90% Si	7202.21.9000	5.8% ad val.	40.0% ad val.
Ferrosilicon, other:			
Ferrosilicon, more than 2% Mg	7202.29.0010	Free	4.4¢/kg Si.
Ferrosilicon, other	7202.29.0050	Free	4.4¢/kg Si.
Silicon, more than 99.99% Si	2804.61.0000	3.7% ad val.	25.0% ad val.
Silicon, 99.00%–99.99% Si	2804.69.1000	5.3% ad val.	21.0% ad val.
Silicon, other	2804.69.5000	9.0% ad val.	45.0% ad val.

[1] Tariff effective Jan. 1, 1989.

In accordance with the United States-Canadian Free Trade Agreement, U.S. duties on ferrosilicon products imported from Canada were removed on January 1, 1989. Also effective on January 1, duties on Canadian silicon metal imports were lowered. Duties on all grades of metal were scheduled to be eliminated by 1998.[8] The new U.S. duty rates per kilogram of silicon metal originating in Canada were as follows:

Year[1]	Harmonized Tariff Code		
	2804.61.00	2804.61.10	2804.69.50
1989	2.9%	4.7%	8.1%
1990	2.2%	4.2%	7.2%
1991	1.4%	3.7%	6.3%
1992	.7%	3.1%	5.4%
1993	Free	2.6%	4.5%
1994	Free	2.1%	3.6%
1995	Free	1.5%	2.7%
1996	Free	1.0%	1.8%
1997	Free	.5%	.9%
1998	Free	Free	Free

[1] Rates of duty effective Jan. 1, 1989.

In April, the Office of the U.S. Trade Representative (USTR) released its 1988 Product Review of the Generalized System of Preference. The U.S. Ferroalloy Association had requested an end to duty-free imports of 99.00 to 99.99% silicon metal from Argentina and Yugoslavia. The USTR decided to continue Generalized System of Preference (GSP) status of these imports. However, effective July 1, 1989, the USTR removed GSP status of Brazilian silicon metal less than 99.99% but not less than 99% silicon and ferrosilicon containing by weight more than 55% but less than 80% silicon and more than 3% calcium.[9]

Late in 1989, the Office of Foreign Availability, Bureau of Export Administration, Deptartment of Commerce, began an investigation to assess the foreign availability of high purity polycrystalline rods and chunks. These materials were the basic raw materials for most semiconductor devices in 1989. Subsequently, the sale of these materials was regulated for national security reasons. A decision on this investigation was pending at yearend.[10]

WORLD REVIEW

Australia

Barrack Mines Ltd. successfully commissioned its silicon metal plant near Perth, Western Australia. When fully operational, the furnaces were reported to be capable of producing 36,400 tpy of silicon metal. However, the production output for 1990 was targeted at 27,600 short tons. Silicon metal from these furnaces was expected to meet the stringent purity requirements of the primary aluminum and chemical industries. Barrack was reported to have long term contracts with both Thyssen Handesunion AG, West Germany, and Dow Corning Corp., Midland, MI. The company also had announced plans for an additional two furnaces scheduled for start up in July 1991.[11]

Brazil

Brazilian ferroalloy producers announced several expansions and expansion plans during 1989. However, because of poor market conditions in the second half of 1989, the completions of these plans were in question.[12]

Electrovale SA Industria e Comercio, a Brazilian-Japanese joint venture, began construction of a 31 MV•A furnace at its Nova Era Works, Minas Gerais state. The expansion was expected to double the output of 75%-grade ferrosilicon from 26,500 to 55,100 tpy.[13]

Late in the year, Cia. de Ferro Ligas da Bahia (Ferbasa) began a project to convert five 75%-grade ferrosilicon furnaces to produce silicomanganese. The company also planned to build four hydroelectric plants in Bahia. The first two plants were planned for completion in 1992.[14]

Cia. Ferroligas Minas Gerais (Minas Ligas) moved into silicon metal production for the first time in 1989. The company commissioned a 15 MV•A furnace at its Pirapora site. The new furnace was provided by Delp Engenharia Mecancia, Minas Ligas' parent company. Minas Ligas also planned to start up a second furnace in 1990. Because of escalating energy costs, Minas Ligas conducted feasibility studies into constructing its own hydroelectric plant at Retiro.[15]

Cia. Paulista de Ferro Ligas delayed its move into ferrosilicon production until late 1991. Two 18-MV•A furnaces were planned for installation at Cia Paulista's subsidiary, Electrosiderúrgica Brasileira SA (Sibra).[16]

Camargo Corrêa Metais started production at its second 18-MV•A silicon metal furnace at Tucurui, Para State in northern Brazil. The first 18-MV•A furnace was commissioned in 1988. A third and fourth furnace were near completion at yearend. The furnaces were manufactured by the Demag Corporation. Production from the furnaces was intended for export.

Italmagnésio SA Industria e Comércio made plans to double its existing capacity to produce 75%-grade ferrosilicon. The plan included the installation of 24-MV•A and 6-MV•A furnaces.[17]

Multisilicon, a new Brazilian company, announced a project aimed at producing 27,600–30,900 tpy of chemical and metallurgical grade silicon metal at Leopoldina, Minas Gerais.

TABLE 4

U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
FERROSILICON			
Over 55% silicon:			
Canada	3,309	1,985	$2,486
Japan	5,042	2,948	3,846
Korea, Republic of	7,595	5,334	5,906
Mexico	2,747	1,649	2,018
Taiwan	1,935	1,194	1,870
Other (18 countries)	2,669	1,627	2,136
Total[1]	23,297	14,738	18,262
Other ferrosilicon:			
Australia	1,735	868	1,244
Canada	11,200	5,600	8,008
Japan	2,063	1,031	1,714
Mexico	1,631	815	1,189
United Kingdom	8,017	4,008	5,756
Other (25 countries)	6,114	3,057	4,668
Total[1]	30,760	15,380	22,580
Total ferrosilicon[1]	54,056	30,117	40,842
SILICON METAL			
Over 99.99% silicon:			
Denmark	46	NA	3,191
Italy	99	NA	4,190
Japan	534	NA	27,235
Korea, Republic of	30	NA	1,463
Malaysia	220	NA	35,698
Other (29 countries)	78	NA	3,490
Total[1]	1,007	XX	75,266
99.00%-99.99% silicon:			
Italy	299	NA	684
Mexico	159	NA	233
Saudi Arabia	184	NA	189
South Africa, Republic of	105	NA	116
Taiwan	106	NA	111
Other (17 countries)	452	NA	936
Total[1]	1,305	XX	2,269
Other silicon:			
Canada	570	NA	537
Mexico	548	NA	1,501
Netherlands	602	NA	709
New Zealand	287	NA	376
Venezuela	717	NA	768
Other (36 countries)	524	NA	2,648
Total[1]	3,249	XX	6,539
Total silicon metal[1]	5,561	XX	84,074

NA Not available. XX Not applicable.

[1] Data may not add to totals shown because of individual rounding of converted units.

Source: Bureau of the Census.

The project was scheduled for completion by 1991. Prior to construction, the company had obtained a 10-year sales contract with Dow Corning Corp., Midland, MI. Multisilicon intended to export the majority of its production. Initial plans called for two 18-MV•A furnaces.[18]

The Rima group was reported to have brought two silicon metal furnaces on-line in Minas Gerais state. Rima also began construction of a 50-MV•A hydroelectric plant at Rodeado. The electric plant was intended to help provide a small portion of the plant's enormous energy needs.[19]

Canada

SKW Canada Inc. shut down one of its furnaces for repair late in 1989. The furnace was not expected to return to full capacity for at least a 6-month period.

India

VBC Ferro Alloys Ltd. upgraded its ferrosilicon capacity from 11,000 to 16,500 tpy. Nav Bharat Ferroalloys Ltd. sought permission from the Indian Government for an additional 11,000 tpy of ferrosilicon capacity. Ispat Alloys Ltd. was in the process of installing a silicon metal furnace to increase its capacity to 22,000 tpy. In an effort to alleviate problems with electrical power cutbacks, several companies began projects to build captive power plants.[20]

Iran

The Iran Ferro-Alloy Co. scheduled the opening of Iran's first ferrosilicon plant for early 1991. The new facility was being constructed in Azna within the western province of Luristan. The plant was expected to produce 27,600 tpy of ferrosilicon for domestic consumption. Technical support for the project was to be provided by Elkem Technology AS.[21]

Japan

Effective in August 1989, Japanese steelmaker NKK Corp. sold its interest in the ferrosilicon producer Yakushima Denko Co. Ltd. The sale was based on a decision by the company to rely on imports for ferrosilicon. The Brazilian ferroalloy producer Ferro Ligas Assofon SA, of which NKK held a 27% portion of ownership, was expected to

fulfil a large portion of the company's ferrosilicon needs.[22]

Denal Silane Co. Ltd. completed a state-of-the-art monosilane plant at Omi. Denal was a joint venture between Denki Kagaku Kogyo KK and the L'air Liquide Group. The plant was reported to be the largest merchant producer of monosilane and was capable of producing monosilane at the parts per billion (ppb) purity level.[23]

Norway

Elkem A/S reorganized its global management structure from geographic divisions to a product based organization. In order to give the company a firmer footing in the European aluminum industry and to boost its downstream involvement, Elkem increased its share in Alcoa Nederland BV from 25% to 50%. Late in 1989, Elkem announced it would maintain its worldwide ferrosilicon production level in the coming year. Elkem also announced plans to purchase the remaining interest in Bjølvefossen AS. During 1989, Bjølvefossen operated four ferrosilicon furnaces at its facility in Ålvik.[24]

In December, Fesil KS announced plans to reduce its Norwegian ferrosilicon production by 11,000 tons to 16,500 tpy. The company planned to idle one of its furnaces at Ila og Lilleby Smelteverker and begin a furnace maintenance program at its Hafslund facility. The company delayed bringing ferrosilicon furnaces on-stream at its Mo I Rana facility.[25]

Philippines

Mindanao Ferroalloys Co. (Minfaco) was formed as a joint venture between Maria Cristina Chemicals Industries (MCCI), Sangyong Co. Ltd., Pohang Iron and Steel Co. (Posco), and Dongil Chungong Co. Ltd. The new company planned to convert a 27-MV•A carbide furnace at MCCI's plant on the island of Mindanao to producing ferrosilicon. The estimated 14,300 tpy of new capacity was scheduled for startup in mid-1991. Production from this facility was intended for export to the Republic of South Korea.[26]

Portugal

Brazilian Italmagnésio Group formed a new subsidiary in Portugal called Novos Fornas de Beira Alta Lda. (Forbel). In a 10-year rental agreement with So-

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
FERROSILICON			
55%–80% silicon, over 3% Ca:			
Argentina	1,188	705	$1,428
Belgium	74	45	96
Brazil	16,926	10,499	20,879
France	3,125	1,908	4,354
Germany, Federal Republic of	121	78	306
Italy	808	502	1,027
Japan	207	157	439
Spain	60	35	78
Total[1]	22,510	13,929	28,607
55%–80% silicon, other:			
Argentina	9,446	7,180	7,124
Australia	22	17	14
Brazil	15,531	11,421	11,527
Canada	20,208	15,255	15,211
China	1,516	1,025	899
France	595	394	738
Germany, Federal Republic of	472	339	1,550
Iceland	13,846	10,565	7,202
Japan	78	51	205
Norway	13,632	10,347	7,803
Venezuela	28,798	21,680	19,602
Yugoslavia	3,196	2,284	1,037
Total[1]	107,341	80,557	72,912
80%–90% silicon:			
Brazil	15	12	13
France	10	9	22
Total[1]	25	21	35
Over 90% silicon:			
Brazil	2,756	2,545	2,705
China	122	112	119
Hong Kong	118	109	117
Japan	(2)	(2)	1
Total[1]	2,996	2,766	2,941
Magnesium ferrosilicon:			
Brazil	5,804	2,589	3,851
Canada	282	66	104
China	77	25	110
Germany, Federal Republic of	1,139	389	1,848
Japan	31	13	57
Total[1]	7,333	3,082	5,970

See footnotes at end of table.

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
FERROSILICON—Continued			
Other ferrosilicon:			
Brazil	8,485	2,979	$1,967
Canada	8,282	3,740	3,186
Finland	1,126	538	573
France	464	192	465
Germany, Federal Republic of	72	21	75
Japan	37	17	69
Norway	1,003	512	375
U.S.S.R.	36,422	17,706	14,457
Total[1]	55,891	25,704	21,166
Total ferrosilicon[1]	196,096	126,059	131,631
SILICON METAL			
Over 99.99% silicon:			
China	13	NA	133
Denmark	8	NA	396
Finland	(2)	NA	1
France	33	NA	1,174
Germany, Federal Republic of	530	NA	18,686
Italy	210	NA	12,341
Japan	162	NA	2,284
Korea, Republic of	6	NA	112
Malaysia	4	NA	9
Netherlands	1	NA	7
Sweden	(2)	NA	2
United Kingdom	(2)	NA	7
Total[1]	965	XX	35,152
99.00%–99.99% silicon:			
Argentina	7,488	7,420	7,466
Brazil	12,426	12,325	12,610
Canada	7,370	7,306	6,970
China	5,042	4,996	5,172
Denmark	(2)	(2)	2
France	1,485	1,473	1,027
Germany, Federal Republic of	30	30	77
Hong Kong	1,624	1,608	1,700
Italy	100	99	56
Japan	119	118	144
Norway	19	19	38
South Africa, Republic of	853	846	838
Spain	91	90	109
Sweden	41	41	66
Taiwan	184	182	163
Total[1]	36,874	36,553	36,438

See footnotes at end of table.

ciedada Portuguesa de Electrometallurgia SA, the new company restarted ferrosilicon furnaces previously operated by Cia Portuguesa de Fornos Eléctricos S.A.R.L. The operations were capable of producing 33,000 tpy of 75%-grade ferrosilicon. However, a 19-MV•A furnace included in this capacity was being dismantled and sent to Venezuela. Italmagnésio SA Industria e Comercio, which had previously experienced antidumping problems in the European Community, hoped the new subsidiary would give the company a better sales position in the European market.[27]

Venezuelan PT Investment Alloy acquired two 19-MV•A Demag silicon metal furnaces from Portugal's Metalurgia do Norte S.A.R.L. (Milnorte). The furnaces were being dismantled and sent to Venezuela for installation.[28]

Venezuela

Work began on several major ferroalloy projects in 1989. All of the projects revolved around joint-venture agreements with the state development body Corporacion Venezolana de Guayana (CVG). The ventures planned to take advantage of Venezuela's abundant electricity available from CVG's Guri Dam near Puerto Ordaz.

Rima Electrometallurgical SA signed an agreement with CVG to set up a new silicon metal plant in Venezuela. The company reportedly was awaiting an import license from the Venezuelan Government for two new 13,200-tpy silicon metal furnaces. If approved, the furnaces were to be constructed by Rima Mecanica SA in Brazil.

Progress continued on the Guaysil project to produce chemical-grade silicon metal. The project was a Latin-American joint venture between the Rima Group, Cia Minera Autlan SA de CV, and Corporacion Venezolana de Guayana. In 1989, the project received an authorization from the Venezuelan Government for a debt swap arrangement with Venezuela's Morgan Guaranty Bank.

C.V.G. Ferrosilicio de Venezuela CA (Fesilven) started construction of a silicon metal furnace with a scheduled completion within 2 years. Fesilven also planned to install two 32-MV·A furnaces to produce 27,600 tpy of 75%-grade ferrosilicon and modernize two existing furnaces.

Central de Ferroaleacines de Venezuela CA (Cefeca), which had plans for

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
SILICON METAL—Continued			
Other silicon:			
Belgium	3	3	$31
Brazil	4,590	4,498	3,945
Canada	1,028	1,010	990
China	2,970	2,915	2,534
Germany, Federal Republic of	2	2	5
Hong Kong	836	795	856
Italy	3	3	10
Japan	81	80	128
Luxembourg	55	54	57
Norway	34	32	30
Sweden	3	3	21
Taiwan	110	109	112
United Kingdom	60	59	78
Total[1]	9,775	9,560	8,798
Total silicon metal[1]	47,615	347,078	80,388

NA Not available. XX Not applicable.
[1] Data may not add to totals shown because of individual rounding of converted units.
[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 6

WORLD PRODUCTION CAPACITY FOR SILICON-CONTAINING FERROALLOYS AND SILICON METAL IN 1989

(Thousand short tons, contained silicon)

Country	Capacity
Argentina	85
Australia	40
Brazil	350
Bulgaria	(1)
Canada	105
Chile	7
China	400
Colombia	(1)
Czechoslovakia	(1)
Egypt	50
France	170
German Democratic Republic	(1)
Germany, Federal Republic of	50
Hungary	(1)
Iceland	55
India	60
Italy	94
Japan	90
Korea, North	(1)
Korea, Republic of	18
Mexico	19
Norway	457
Peru	(1)
Philippines	25
Poland	(1)
Portugal	13
Romania	(1)
South Africa, Republic of	136
Spain	79
Sweden	50
Switzerland	(1)
Taiwan	15
U.S.S.R.	650
United States	518
Uruguay	(1)
Venezuela	50
Yugoslavia	135
Other	304
Total	4,026

[1] Included with "Other."

no less than 11 new ferroalloy plants, began to purchase equipment for these operations. The Cefeca company, PT Investment Alloy, acquired two 19 MV•A Demag silicon metal furnaces from Metalurgia do Norte S.A.R.L. in Portugal. These furnaces were being dismantled and were planned for installation in 1991. An additional silicon metal furnace was acquired from Portugal's Cia. Portuguesa de Fornas Electricos. The plans called for a total of 76 MV•A of capacity, producing up to 52,900 tpy of silicon metal by 1993. The company also hoped to acquire two Nippon Denko Co. Ltd. furnaces with capacities of 22 and 33 MV•A for the production of 75%-grade ferrosilicon. These furnaces were scheduled to be brought on-line in 1994.[29]

CURRENT RESEARCH

Engine Components Inc. introduced a silicon carbide coating process for aircraft piston engines designed to expedite ring seating, reduce oil consumption, and increase cylinder service life.[30]

Silicon nitride ceramic valves were produced by the American Ceramic Engine Co., Bolingbrook, IL, for use in stockcar racing engines.[31]

The Duralcan Corp., San Diego, CA, successfully marketed its aluminum and silicon carbide metal matrix composite. The material was sold to Specialized Bicycle Corp. Specialized used the composite material to produce bicycle wheel rims that offered a 40%-higher specific stiffness than unreinforced rims. The company's San Diego pilot plant produced an estimated 100 tons per month in 1989. A 12,500-tpy plant at Jonquiere, Quebec, was under construction and scheduled for completion in 1990. In November, Duralcan cast the largest metal matrix composite (MMC) ingot ever produced. The ingot weighed 1,325 pounds and was composed of an aluminum and silicon carbide composite.

Lanxide Corp., Newark, DE, continued to develop several patented processes that were used to produce ceramic and metal matrix composites. Many of the processes were based on directed metal oxidation and were used to grow metal matrix composites through an oxidation reaction between molten metal and an

adjacent gaseous oxidant. Several of the Lanxide products used silicon carbide reinforcements.[32]

Whole-wafer integrated circuits came to fruition in 1989. Anamaric Ltd. Cambridge, United Kingdom, produced a 6-inch wafer with 202 1-megabyte (MB) dynamic random access memory chips. The success was achieved though the use of control logic to bypass defects on a wafer. The first product based on the wafer-scale integration was a 40-MB solid-state computer disk drive.[33]

Ibis Technology Corp., Danvers, MA, used a new process called Separation by Implantation of Oxygen (SIMOX) to bury oxygen ions just below the surface of a standard silicon wafer. As a result of this process, circuits printed on the SIMOX chip ran 30% faster than an ordinary silicon chip. The SIMOX process implants a layer of silicon dioxide in the chip, which insulates the circuits from stray capacitances and currents triggered by radiation or high temperatures. The SIMOX process was originally developed by Harris Semiconductor, Melbourne, FL, for military and space applications. Ibis produced SIMOX wafers for commercial applications commercially.[34]

In 1989, micromechanics emerged as a viable industry. Researchers used techniques used to produce computer chips to carve out minuscule devices only two-thirds the width of a human hair. Although these devices included mechanisms such as micromotors and microswitches, commercial success was achieved though microsensors. These sensors were the result of early research efforts by such research centers such as AT&T Bell Labs, Murray Hill, NJ; Stanford University, Stanford, CA; and Massachusetts Institute of Technology, Cambridge, MA. The largest producer of these sensors was Delco Electronics Corp, Kokomo, IN. Delco incorporated the sensors into controls and diagnostics for automobile engines and transmissions. Future applications for the sensors included antilock braking, dynamic suspension, crashbag activation, and tire pressure monitoring.[35]

Dow Corning Corp., Midland, MI, proceeded with plans to develop a process using silica sand to produce silicon metal. After the completion of a $1.1 million feasibility study, Dow made plans to construct a $42 million research facility. The facility was to include a pilot plant to allow further study of the new process. A 25 MV•A furnace producing 30 million pounds-per-year of silicon metal was scheduled for 1994 contingent upon the success of the pilot plant study. If successful, the new process was expected to significantly reduce energy costs and virtually eliminate the need for consumable electrodes normally associated with silicon metal production.[36]

Researchers at Sandia National Laboratories in New Mexico achieved a record solar to electric conversion efficiency ratio of 20.3% using a silicon-base photovoltaic concentrator module. The module consisted of 12 lenses that concentrate concentrated sunlight over several hundred times onto silicon solar cells. A commercial product using these cells was expected within three years.[37]

OUTLOOK

Demand for silicon metal is driven by the aluminum and the chemical industries. Consumption by the aluminum industry, which uses silicon as an alloying agent, is expected to undergo slow growth over the next 5 years. The increased use of aluminum in automobiles, which reached a record high in 1989, will contribute to this growth. Additionally, a trend toward the use of higher silicon content in aluminum castings is expected to continue. The chemicals industry consumes silicon metal to produce a wide variety of compounds such as silanes, silicone resins, and lubricants. In the past, this industry has shown steady growth and is expected to continue this trend.

Ferrosilicon is consumed primarily by the iron and steel industry. The industry uses ferrosilicon for both deoxidation of molten metal and as an alloying agent. The American Iron and Steel Institute studied the consumption of steel by industrialized countries and predicted an average decline of 0.1% per year from 1985–95. Subsequently, ferrosilicon consumption is not expected to grow over the next 5 years.[38] However, several factors could influence consumption of ferrosilicon by the steel industry. These factors may include possible technological advances, environmental legislation, and trade agreements.

Production cutbacks were scheduled by many producers in the latter half of 1989. These cutbacks are expected to affect moderate price increases in the coming year. However, average prices are not expected to rise appreciably over the long term because of increases in worldwide capacity.

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